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Space Vector Pulse –Width Modulation for a Balanced Two Phase Induction Motor –A Detailed Study

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Abstract—**This paper deals with the mechanism of space –vector pulse –width modulation (SVPWM) for a balanced two –phase induction motor ,in detail .It explains how the wave-forms of the voltages applied to the two phases derive from the SVPWM .**

Index Terms—**Balanced two phase induction motors, space –vectors,SVPWM,Sampling time ,Total harmonic distortion.**

I. Introduction

The concept of space –vector and space –vector pulse –width modulation has been dealt with in connection with three –phase induction motors for more than two decades now. Attention has been given to two –phase induction motors also [1]-[7].A scheme for SVPWM for a balanced two phase induction motor, using a separate H- Bridge for each phase has been discussed by the present authors in an earlier paper [8]. This paper continues the discussion. It goes into the mechanism of generating a particular space vectors on an average basis over a sampling time T_s producing a desired averaging effect. The derivation of the waveform of the voltages applied to the phases as a consequence of the switching sequences followed over successive sampling times is presented. These waveforms are subjected to fourier analysis. The fundamental components as well as total harmonic distortion are calculated.

II. Excitation Of Balanced Two Phase Induction Motor Using Two H-Bridge Inverters

This scheme which is almost self-suggesting and evident is shown in fig.1. The DC voltage inputV_d shown here is usually itself an output of an AC-DC converter with the three phase utility supply as an input. The two phase windings A_1A_2 and B_1B_2 are shown perpendicular to each other to indicate that the space vectors they produce are perpendicular to each other in the air gap space in which the rotor rotates. In fact, it is this space in which the desired space vector is defined. The gating arrangements for the controlled switches and other details which are not needed for our discussion are omitted from this fig 1. to keep it as simple as needed. The pairs of controlled switches Q_1Q_1' and $Q_2Q'_2$ for bridge no1. are complimentary.

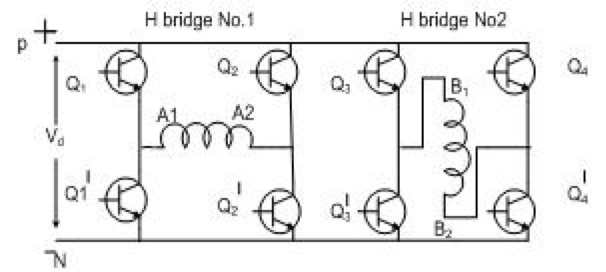

Fig 1. Excitation for a two phase motor

With Q_1 and Q_2 both on, both the terminals A_1 & A_2 of phase A are tied to the positive terminal P of V_d. Hence $V_{A1A2}= 0$. Similarly if Q_1 & Q_2 are both off, both A_1 & A_2 are tied to the negative terminal N of V_d. Again $V_{A1A2}=0$. If Q_1 is on and Q_2 is off, A_1 is connected to P & A_2 is connected to N. Here $V\text{-}_{A1A2} = +V_d$. Lastly if $Q_1$is off and $Q_2$is on, A_1 is connected to N & A_2 is connected to P. At this time $V_{A1A2} = -V_d$.The four possible switching combinations discussed gives the following space vectors from bridge no 1. As given in table no I. Similar analysis for Bridge no 2 gives the four space vectors of table no II.

Table I. Space vectors of H bridge 1

Q_1	Q_2	Magnitude
P	P	0
P	O	$V_d \angle 0$
O	P	$V_d \angle -\pi$
O	O	0

Table II. Space vectors of H bridge 2

Table 2		
Q_3	Q_4	Magnitude
P	P	0
P	O	$jV_d=V_d \angle \pi/2$
O	P	$-jV_d=V_d \angle -\pi/2$
O	O	0

The space vectors of bridge 1 & 2 are shown in fig 2(a) & 2(b) separately and then together in fig 2(c). The space vectors of bridges 1 & 2carry subscript 1& 2 respectively. Each bridge gives us four possible space vectors (two of them being zero). Of course at any time only one of these is available

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from a bridge.

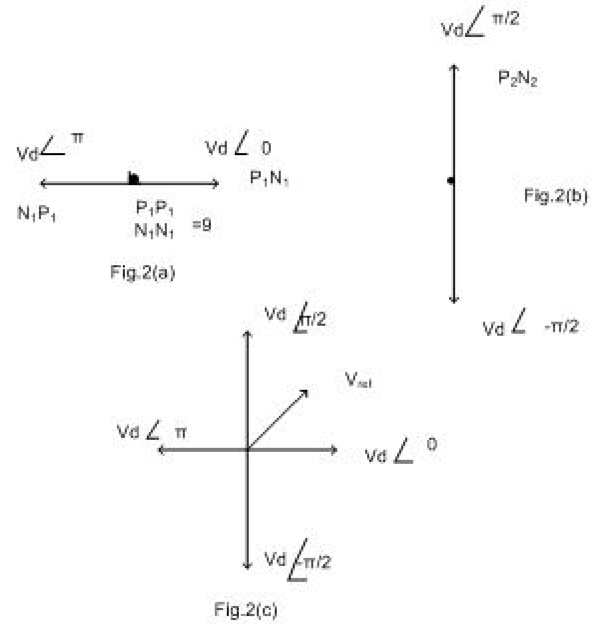

Fig 2. Space vectors available from the two bridges

III. The Modus Operands Of Svpwm

The starting point of induction motor is a voltage space vector rotating in a space. Such a space vector is produced in an analog fashion by a three phase supply available from the electric grid. The space vector pulse width modulation technique attempts to emulate this rotating space vector through the use of DC input V_d and controlled switches available in the H-Bridges. The upside of the scheme is that the magnitude and the rotational speed are dictated by us. The downside of this scheme is that the rotation is not analog smooth. It takes place in jumps.

To understand the implication of the mechanism of the space vector PWM, let it be assumed that at certain time 't' the desired space vector is $V_{ref} \angle \theta$ as shown in fig 2 (c). The value of θ considered is shown to be in the 1st quadrant of the θ space. But the analysis is later extended to all the four quadrants. It can be seen that,

$$V_{ref} \angle \theta = V_{ref} \cos\theta + jV_{ref} \sin\theta \qquad (1)$$

Bridge no.1 can give us a space vector V_d (with Q_1 on & Q_2 off) or zero with (both Q_1 & Q_2 off). The value of $V_{ref}\cos\theta$ is obtained from bridge 1 as an average over a sampling period T_s. If the output V_d is made available from bridge no 1. for a period $T_A < T_S$ and kept zero for remaining part of T_s, the average output is

$$(V_d T_A)/T_s = V_{ref}\cos\theta \qquad (2)$$

$$T_A/T_S = V_{ref}\cos\theta / V_d \qquad (3)$$

Equation (3) gives maximum values of V_{ref} as

$$V_{refmax} = V_d \qquad (4)$$

A modulation index m_a is defined as

$$m_a = V_{ref}/V_d \ (\leq 1) \qquad (5)$$

Thus,

$$T_A/T_S = m_a \cos\theta \qquad (6)$$

Similar analysis of bridge 2 gives an expression for T_B/T_S as,

$$T_B/T_S = m_a \sin\theta \qquad (7)$$

where $T_B<T_s$ is the period for which bridge 2 gives an output of jV_d. The analysis shows that for a sampling period T_S, the pulse widths are adjusted as T_A & T_B for the two bridges, where as the height of the pulse is constant as V_d. The placing of the active portion T_A & T_B during the sampling period can be done in infinitely many ways. But the spacing of these periods T_A & T_B at the centre of the sampling period T_S is the best choice.

IV. Switchin Sequences For Different Quadrants

Equation (1) is valid for all quadrants.. However for quadrants 2 & 3 cosθ is negative. This means that bridge no.1 has to produce a negative output $-V_d$ during the active period T_A. For this duration of T_A, Q_1 should be off and Q_2 should be on. The expression T_A/T_s has to be modified as.

$$T_A/T_S = m_a |\cos\theta| \qquad (8)$$

Similarly for θ in quadrant 3 & 4 $V_d \sin\theta$ is negative. This means that in these quadrants bridge no 2 gives a negative output over the active period T_B with Q_3 off & Q_4 on. The expression for T_B/T_S

$$T_B/T_S = m_a |\sin\theta| \qquad (9)$$

Equation 8 & 9 are valid for all quadrants.

With T_A & T_B calculated the switching sequences (for θ in all the four quadrants) for bridges 1 & 2 are given in table III.

Table III. Switching sequence for bridges 1 and 2

Location of θ		Bridge 1				Bridge 2		
		$(T_s-T_A)/2$	T_A	$(T_s-T_A)/2$		$(T_s-T_A)/2$	T_B	$(T_s-T_B)/2$
1st Quadrant	Q_1	0	1	0	Q_3	0	1	0
	Q_2	0	0	0	Q_4	0	0	0
2nd quadrant	Q_1	0	0	0	Q_3	0	1	0
	Q_2	0	1	0	Q_4	0	0	0
3rd quadrant	Q_1	0	0	0	Q_3	0	0	0
	Q_2	0	1	0	Q_4	0	1	0
4th quadrant	Q_1	0	1	0	Q_3	0	0	0
	Q_2	0	0	0	Q_4	0	1	0

V. Choice Of Sampling Time

The average effect remains unchanged over a sampling time. This means effectively that θ is frozen at a constant value over T_S. A new value of θ will be assigned for the next sampling time T_S. This means that the method of SVPWM produces a rotating effect in discrete jumps. This gives rise to the question, how many jumps per revolution (electrical) should be chosen. The answer to this question cannot be unique, but to be practically answered on the basis of the range of speed control intended and on the ability of

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producing of their pulse width s that may be needed.

For 50 Hz motors the periodic time is 20 ms, 20,000 μsec, and it is possible to divide this time into upto 20 sampling times of 1000μseconds each. The frequency corresponding to this choice will correspond to20 *50= 1000 Hz. The ratio of this switching frequency fsw to the fundamental frequency intended is frequency modulation index($m_{f).}$In the choice mentioned above mf =1000/50=20.

VI. Determination Of The Phase Voltage Waveforms

Choosing m_f = 12 and m_a = 0.8 the waveforms for phase A and phase B can be generated by going through the switching sequences given in table 1.Vd is normalized as 1.

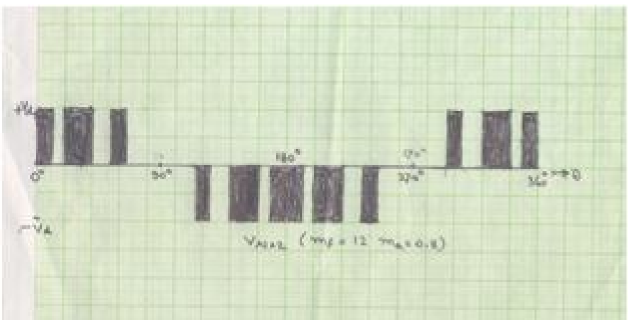

Fig 3(a) Waveform for V_{A1A2}

Then for phase A ,for the first pulse (T_s=1000 μs)taking e=0 ,the pulse width is 0.8cos θ Tsi.e. (800 μsec).For the next pulse, the pulse width is 0.8cos30Ts=0.6928Ts= 692.8 μsec. This can be continued, and placing these active periods at the centre of each pulse, the waveform for V_{A1A2} is obtained as shown in fig. 3(a). Similar procedure can give the phase 2 voltage V_{B1B2} also. The Fourier analysis of this waveform gives the results in (fig. 3b)

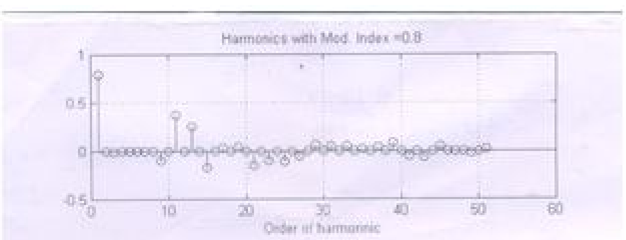

Fig 3(b) Fourier Analysis of waveform V_{A1A2}

The rms value=0.7050.The rms value for the fundamental =0.15626.Hence THD=75.64%. As a result of a convenient value of mf =12 there are no even harmonics in the output. By looking at the switching sequences in quadrant 1,3 and 2,4 it is seen. that V_{A1A2} $(\theta+\pi)$ = V_{A1A2} (θ) This means that the output has rotational symmetry and hence does not contain even harmonics for chosen value of mf.

Conclusion

The mechanism of space –vector pulse-width modulation is studied in detail, especially for a two –phase balanced induction motor .The advantage of control over magnitude and frequency is brought out. The down side disadvantage of discrete jumps in the rotation of space-vectors is brought out. The issue of deciding the sampling time T_s and associated frequency modulation m_f is discussed .A typical waveform for the voltage input of a phase is generated and analysed for distortion .The absence of even harmonics in these output is brought out.

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